First ADS analysis of B⁻→D⁰K⁻ decays in hadron collisions

Paola Garosi
(University of Siena & INFN Pisa)
for the CDF collaboration

DISCRETE 2010
Symposium on Prospects in the Physics of Discrete Symmetries
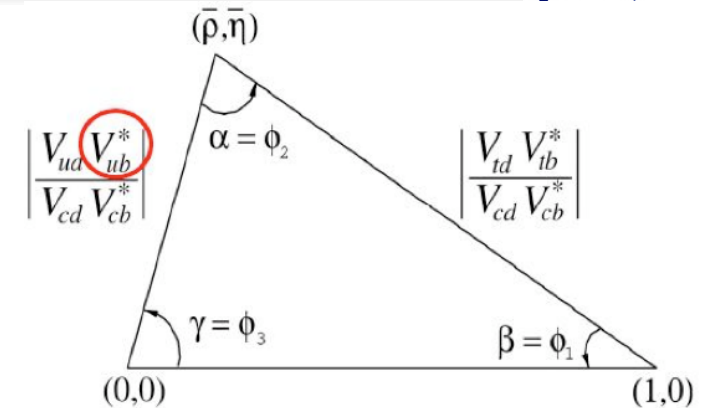**Rome, December 06th-11th 2010**

CKM matrix

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

CP violation if $\eta \neq 0$
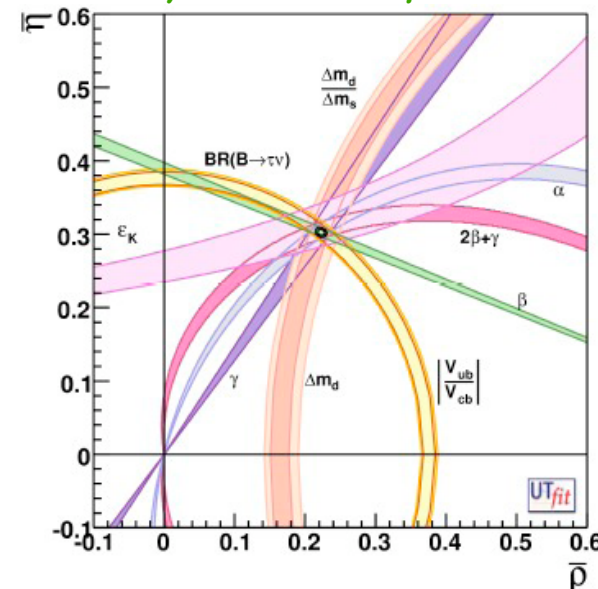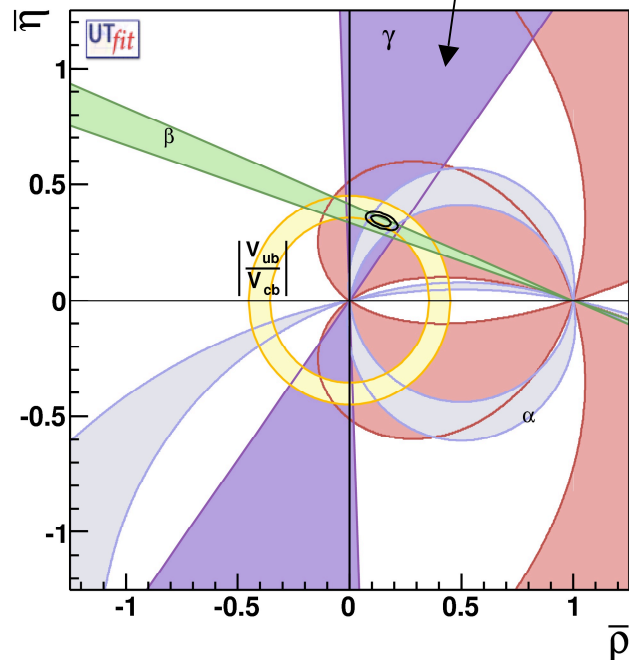
$b \rightarrow u$ transition
B meson system

$(\bar{\rho}, \bar{\eta})$

$\left| \dfrac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right|$ $\quad \alpha = \phi_2 \quad$ $\left| \dfrac{V_{td} V_{tb}^*}{V_{cd} V_{cb}^*} \right|$

$\gamma = \phi_3$ $\qquad\qquad \beta = \phi_1$

$(0,0)$ $\qquad\qquad\qquad (1,0)$

γ is the least well-known angle of the CKM triangle nowadays

Can probe New Physics
(select ρ–η values valid in most of the NP extensions)

Improving the resolution can lead to:
- *consistency with SM prediction*

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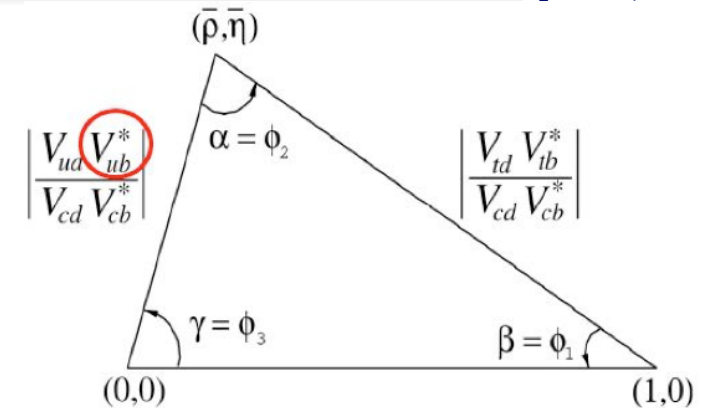CKM matrix

CP violation if η≠0

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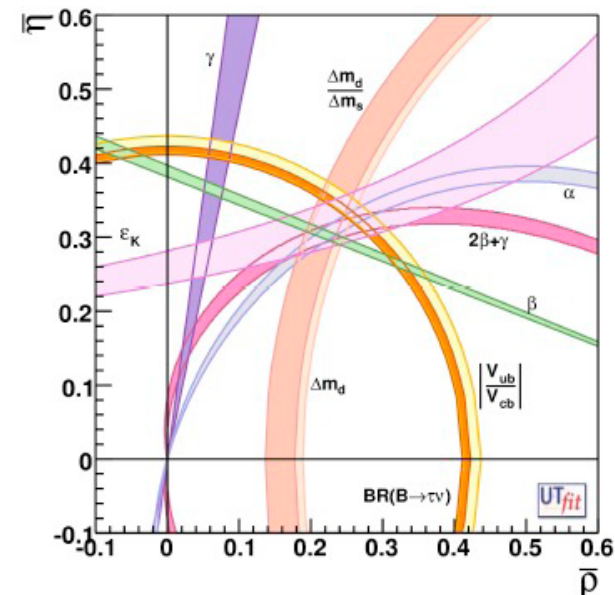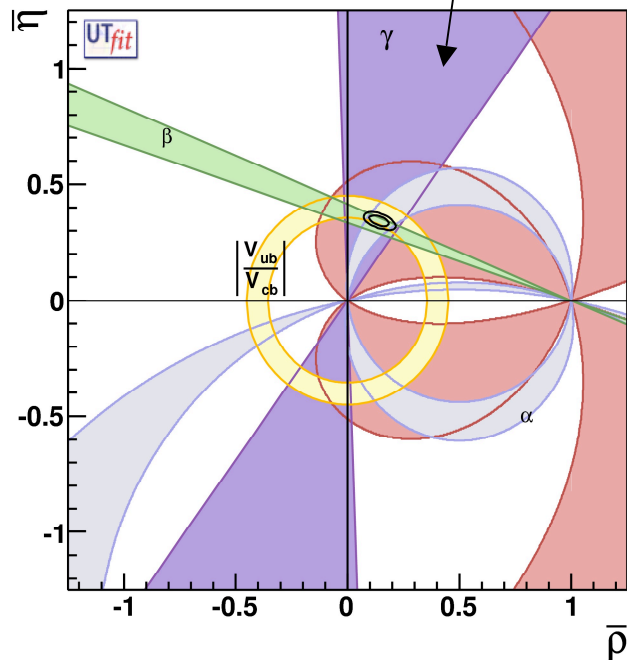
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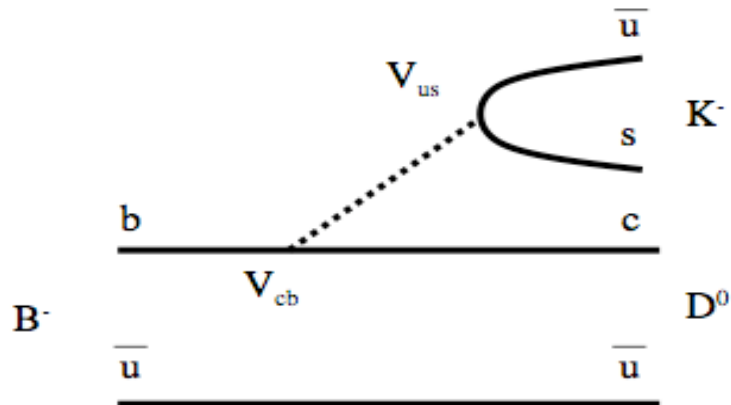- *NP scenario*
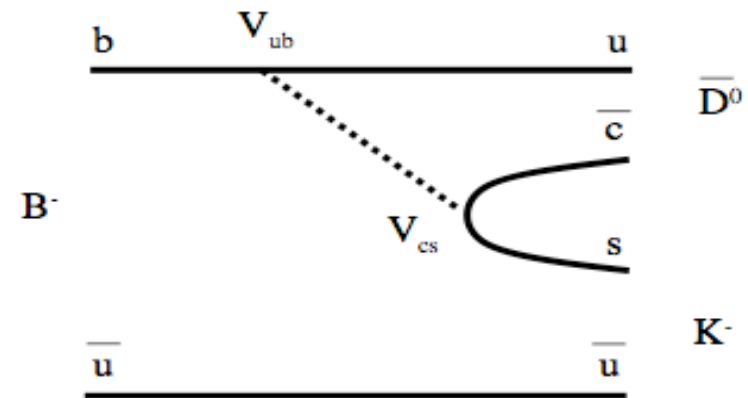

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Use of B→DK decays is the cleanest way to measure γ:
 - tree-level amplitude only
 - tiny theoretical uncertanties

γ can be extracted exploiting the interference between the processes $b \to c\bar{u}s$ ($B^- \to D^0 K^-$) and $b \to u\bar{c}s$ ($B^- \to \bar{D}^0 K^-$), when D^0 and $\bar{D}^0$ decay to the **same final state**

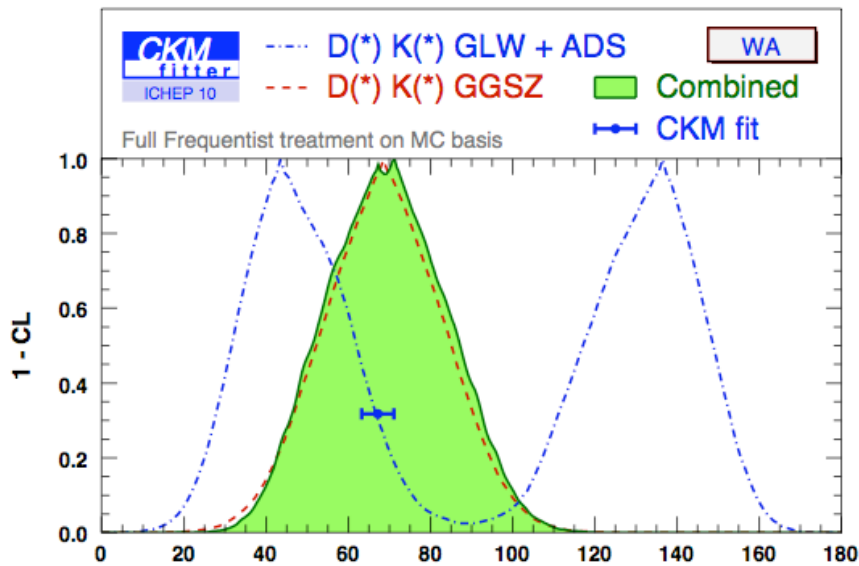Favored $b \to c$ transition

$A_1 \sim V_{cb} V_{us}^* \sim \lambda^3$

Color suppressed $b \to u$ transition

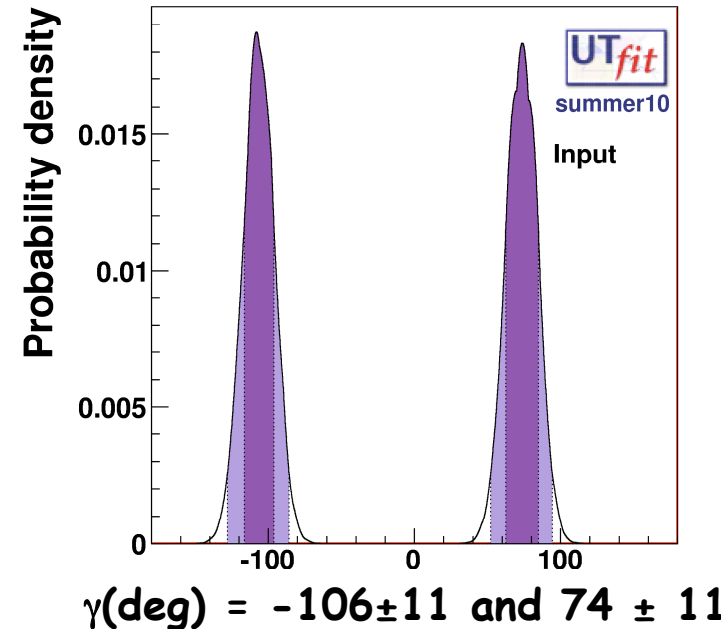$A_2 \sim V_{ub} V_{cs}^* \sim \lambda^3 \, r_B \, e^{-i\delta B} \, e^{-i\gamma}$

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Current situation for the γ angle measurement using $B^- \to D^0 K^-$

$\gamma(\mathrm{deg}) = 71\ [+21\ -25]$

$\gamma(\mathrm{deg}) = -106 \pm 11$ and 74 ± 11

Still large statistical uncertanty

- **GGSZ (Giri-Grossmann-Soffer-Zupan) method** ([PRL78,3257, PRD68,054018])
that uses the $B^{\pm} \to D\ K^{\pm}$ decays with the D^0 and $\bar{D}^0$ reconstructed into three-body final state. For example the $D^0 \to K^0_s\ \pi^+\ \pi^-$

- **GLW (Gronau-London-Wyler) method** ([PLB253,483 PLB265,172])
that uses the $B^{\pm} \to D\ K^{\pm}$ decays with D_{CP} decay modes. $\mathbf{D_{CP+}} \to \pi^+\ \pi^-,\ K^+\ K^-$
and $D_{CP-} \to K^0_s\ \pi^0,\ K^0_s\ \omega,\ K^0_s\ \phi$.

- **ADS (Atwood-Dunietz-Soni) method** ([PRL78,3257;PRD63,036005])
that uses the $B^{\pm} \to D\ K^{\pm}$ decays with D reconstructed in the doubly Cabibbo suppressed
$\mathbf{D^0_{DCS} \to K^+\ \pi^-}$

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ADS method

ADS Observables

Direct CP violation in B → D_{DCS}K modes

- expected large CP asymmetry
- decay suppressed by a factor of ~10^{-3} wrt favored
- results have to be combined with other methods to obtain γ measurement

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Observables

$$R_{ADS}(K) = \frac{N(B^- \to D^0_{DCS}K^-) + N(B^+ \to D^0_{DCS}K^+)}{N(B^- \to D^0_{CF}K^-) + N(B^+ \to D^0_{CF}K^+)}$$

$$\mathcal{A}_{ADS}(K) = \frac{N(B^- \to D^0_{DCS}K^-) - N(B^+ \to D^0_{DCS}K^+)}{N(B^- \to D^0_{DCS}K^-) + N(B^+ \to D^0_{DCS}K^+)}$$

$D^0_{CF} \to K^-\pi^+$, $D^0_{DCS} \to K^+\pi^-$

From theory:

$R_{ADS}(K) = r_D^2 + r_B^2 + 2r_B r_D \cos(\delta_B + \delta_D) \cos\gamma$

$A_{ADS}(K) = 2r_B r_D \sin(\delta_B + \delta_D)\sin\gamma / R_{ADS}(K)$

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$$A_{ADS}(MAX) = \frac{2r_B r_D}{r_B^2 + r_D^2}$$

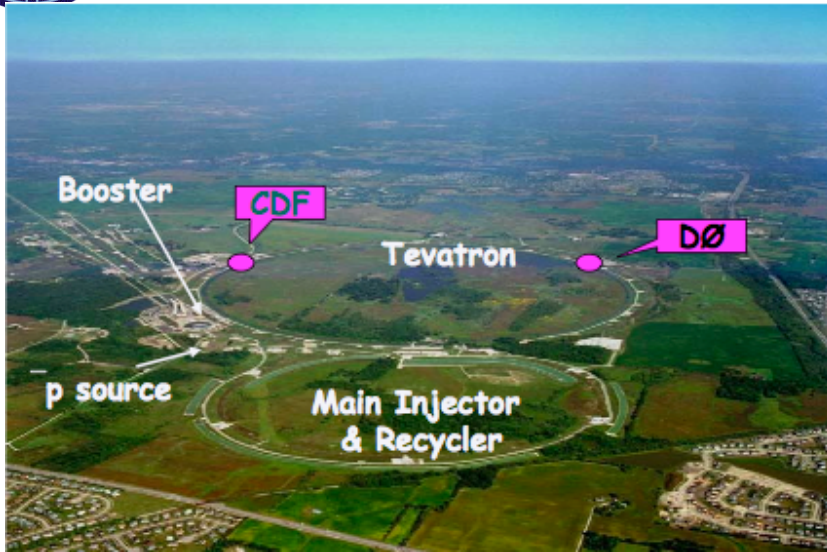$$R_{ADS}(\pi) = \frac{N(B^- \to D^0_{DCS}\pi^-) + N(B^+ \to D^0_{DCS}\pi^+)}{N(B^- \to D^0_{CF}\pi^-) + N(B^+ \to D^0_{CF}\pi^+)}$$

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Sizeable asymmetries may be found also for $B \to D_{DCS}\pi$

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ADS method at CDF

First measurement of A_{ADS} and R_{ADS} at a hadron collider

The Tevatron

Good performances on Run II:
- peak L_{inst} = 3.5-4 10^{32}cm^{-2}s^{-1}
- delivering 2.5 fb^{-1}/year
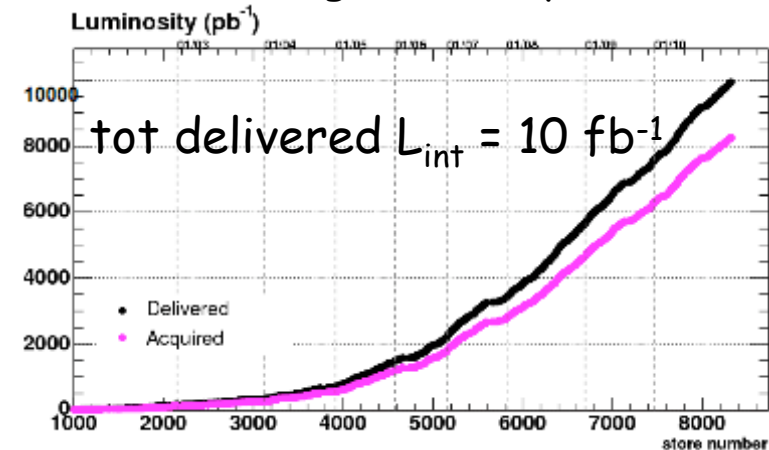
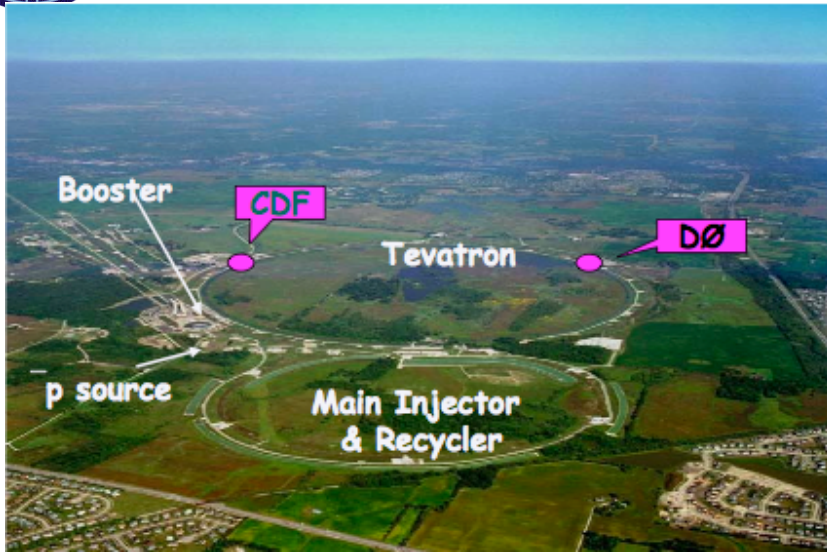tot delivered L_{int} = 10 fb^{-1}

Tevatron is great for rare B decay searches:
- **Enormous b production cross section**
  (x1000 times larger than e^+e^- B factories)
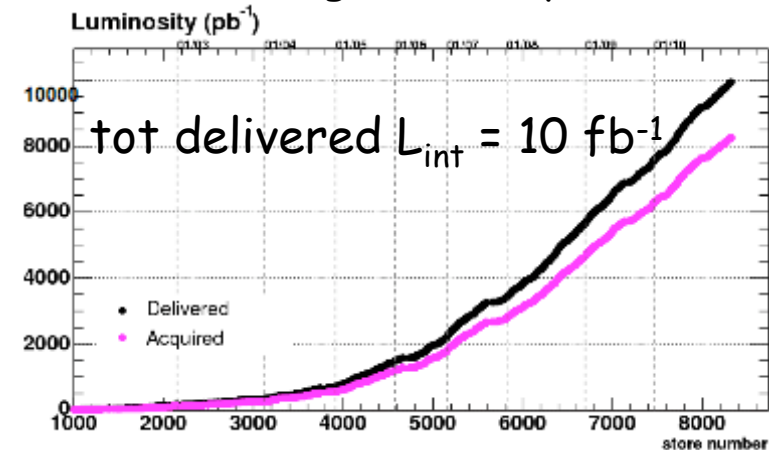- **All B species** are produced (B^0, B^+, B_s, Λ_b...)

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- **All B species** are produced (B^0, B$^+$, B$_s$, Λ_b...)

But:

- The **total** inelastic **x-section** is a factor **10^3** larger than σ(b$\bar{b}$)
- The **BRs** of rare b-hadron decays are **O(10^{-6})** or lower

Interesting events must be extracted from a high track multiplicity environment

CDF
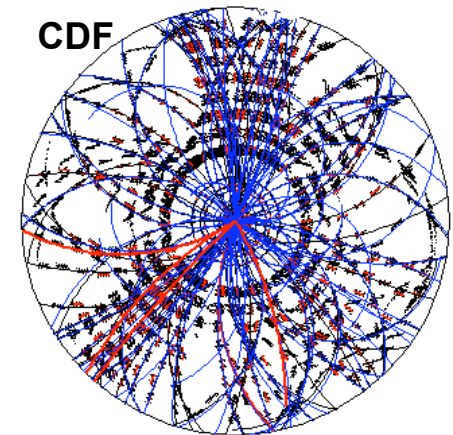
Detectors need to have:
- Very **good tracking** and vertex resolution and **highly selective trigger**

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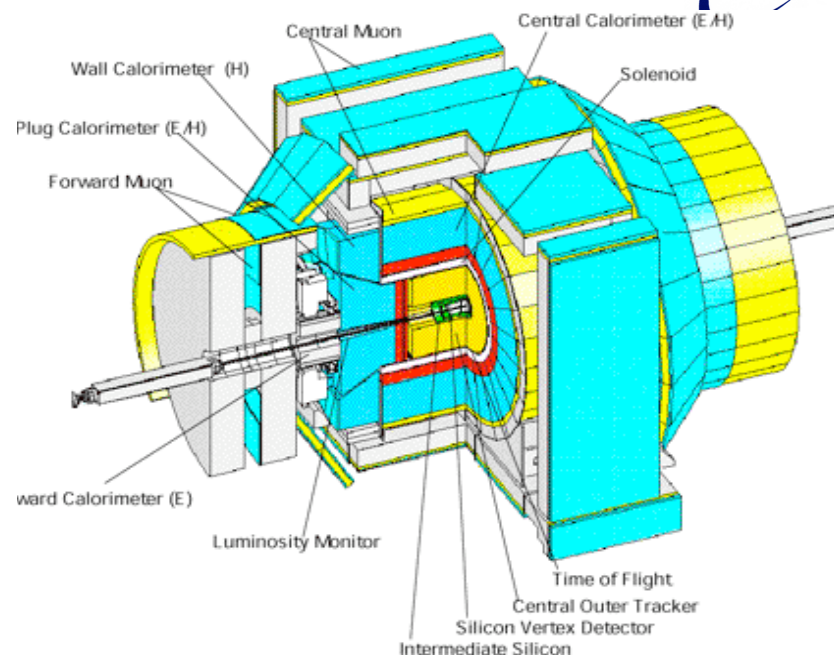**TRACKING system:**

- **DRIFT CHAMBER**
96 layers ($|\eta|<1$)

  $\rightarrow 1.5\sigma$ π/K separation by dE/dx

- **SILICON TRACKER**
7 layers (1.5-22cm from beam pipe)

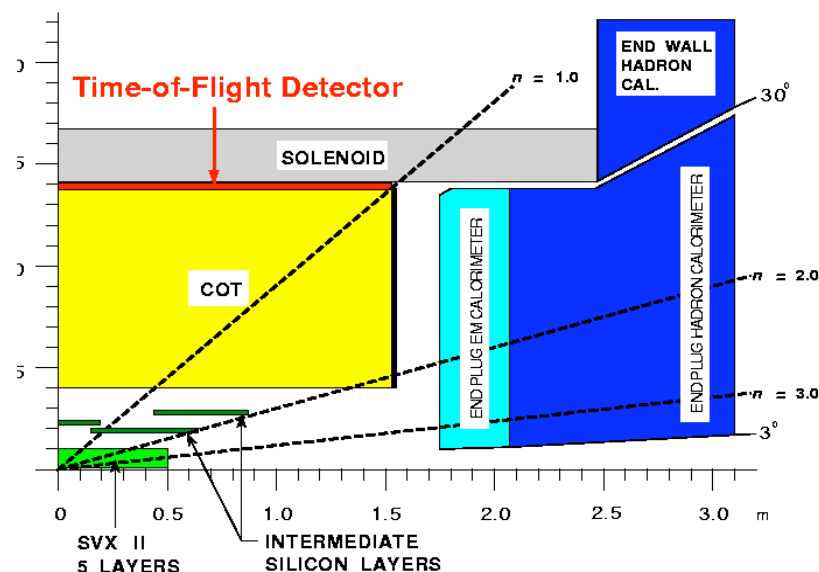 $\rightarrow$ I.P. resolution 35 μm at 2 GeV

  $\rightarrow \sigma(p_T)/p_T^2 \sim 0.015\%$ (c/GeV)

TRACKING TRIGGER system:

- **Chamber track processor** at L1,
2D tracks in COT, $p_T > 1.5$ GeV

- **Silicon Vertex Trigger** at L2,
2D tracks $p_T > 2$ GeV,
Impact Parameter measurement (trigger
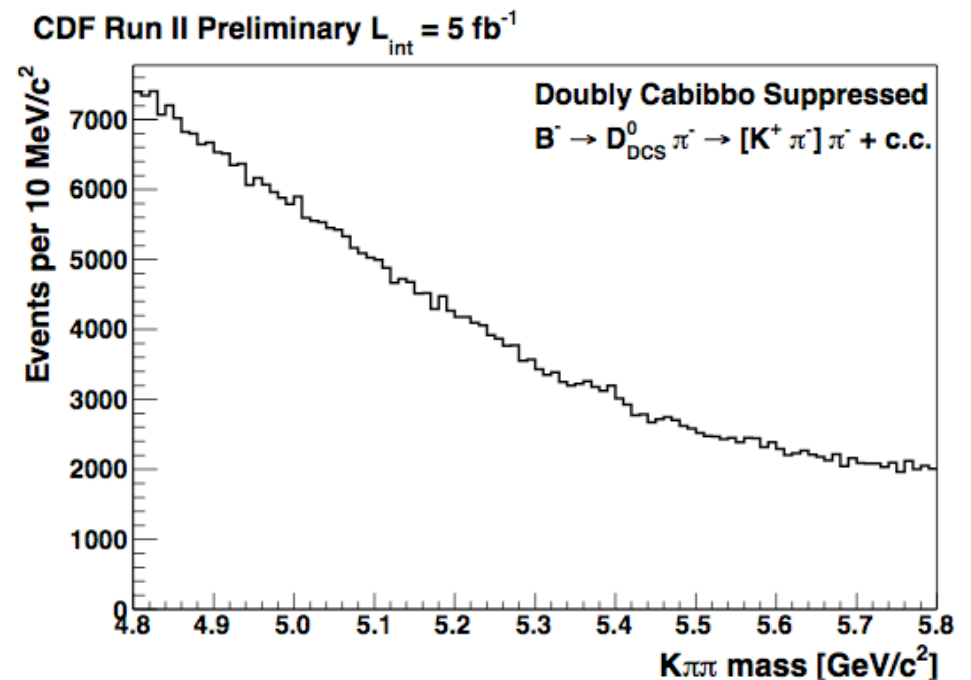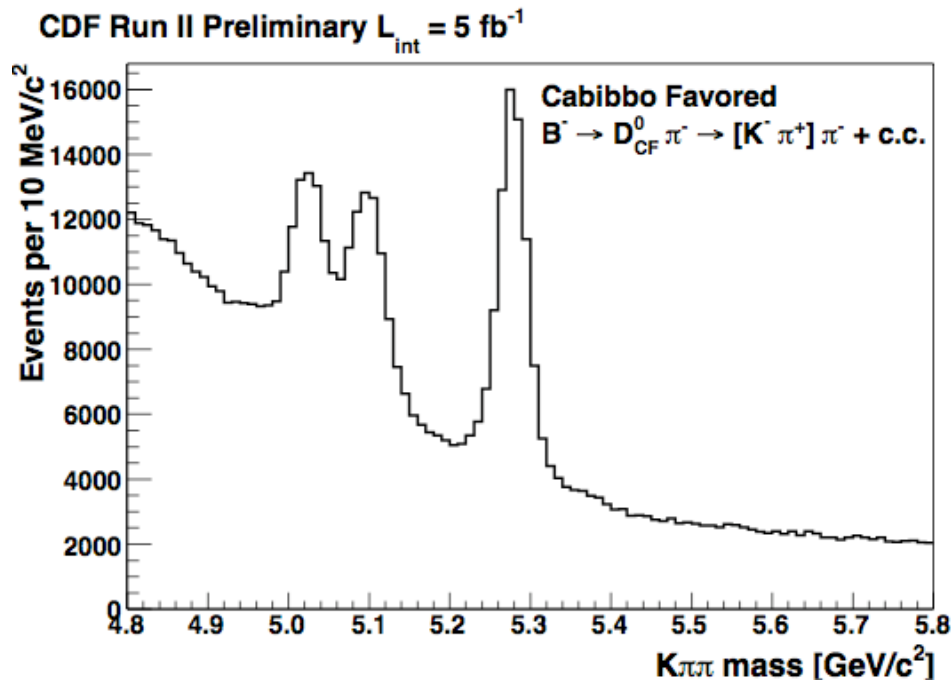on events containing long lived particles)

CF and DCS samples (L = 5fb^{-1})

$B^- \rightarrow D^0_{CF}\, \pi^- \rightarrow [K^-\, \pi^+]\, \pi^-$

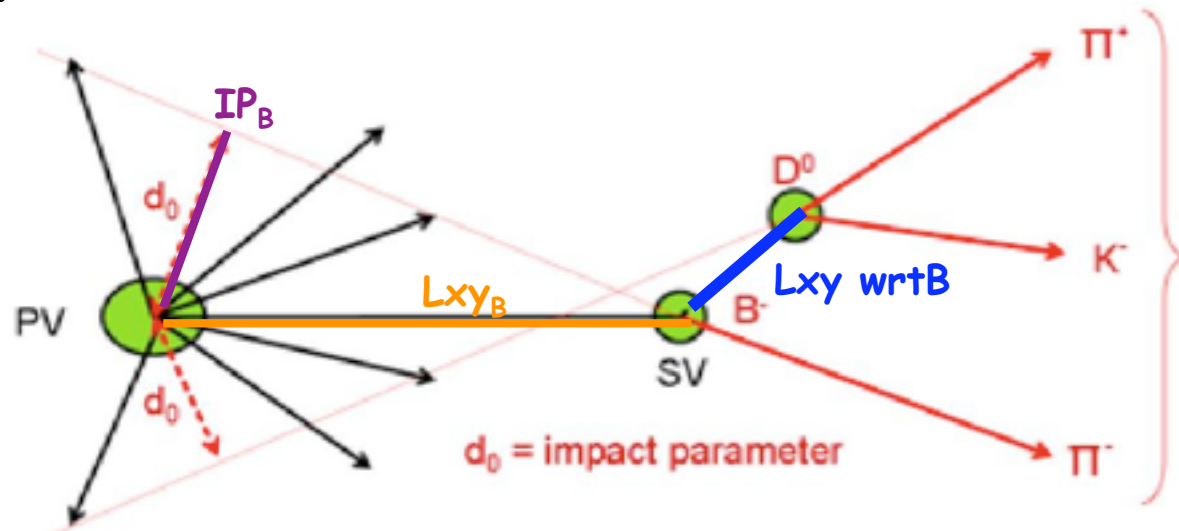$B^- \rightarrow D^0_{DCS}\, \pi^- \rightarrow [K^+\, \pi^-]\, \pi^-$

Cuts optimization ➡ Crucial step toward the DCS modes

• Maximize the quantity $\dfrac{S}{1.5 + \sqrt{B}}$ on CF sample.   (arXiv:0808063v2)

Optimized selection

D⁰ candidate

D⁰ candidate

Cuts on:

• the invariant mass

• angular distribution

• the decay length wrt B to remove B→3 body decays

• particle identification of tracks from D⁰ to remove D⁰→ππ events

IP$_B$

d_0

d_0

PV

Lxy$_B$

d_0 = impact parameter

Lxy wrtB

D⁰

B⁻

SV

π⁺

K⁻

π⁻

B candidate

Cuts on:

- decay length wrt primary vertex

- impact parameter

- angle between momentum and decay length
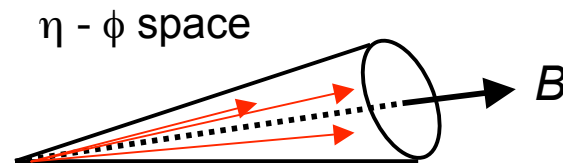
Optimized selection
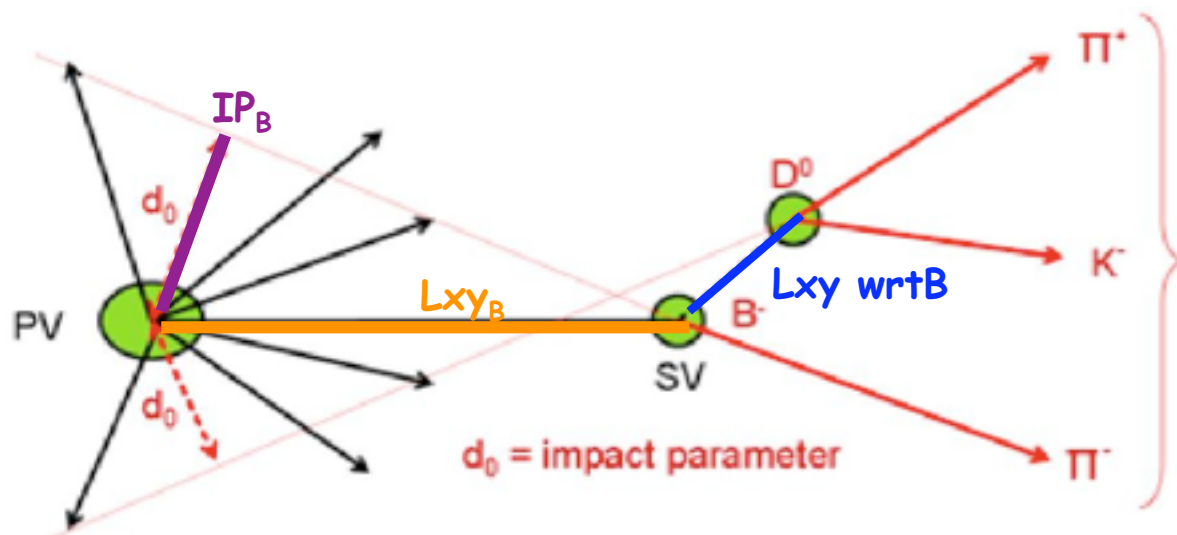
B candidate

Cuts on:

- decay length wrt primary vertex
- impact parameter
- angle between momentum and decay length

- **isolation** $I(B) = \dfrac{p_T(B)}{p_T(B) + \sum_i p_T(i)}$

η - φ space

- **3D vertex quality**, obtained with the 3D silicon-tracking, to:
  - resolve multiple vertices along the beam direction
  - reject fake tracks.

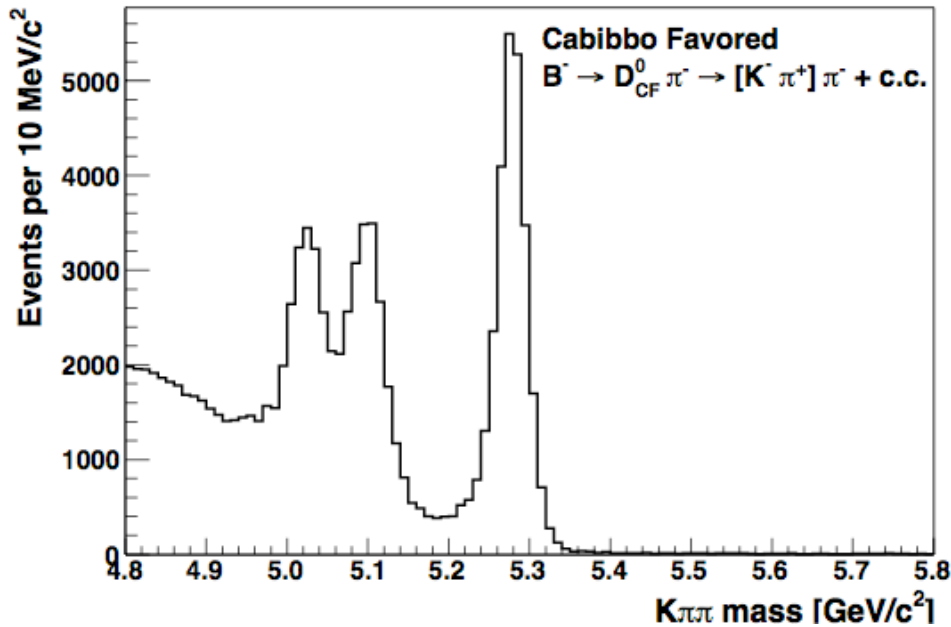Backg. reduces x2, small inefficiency on signal (<10%).
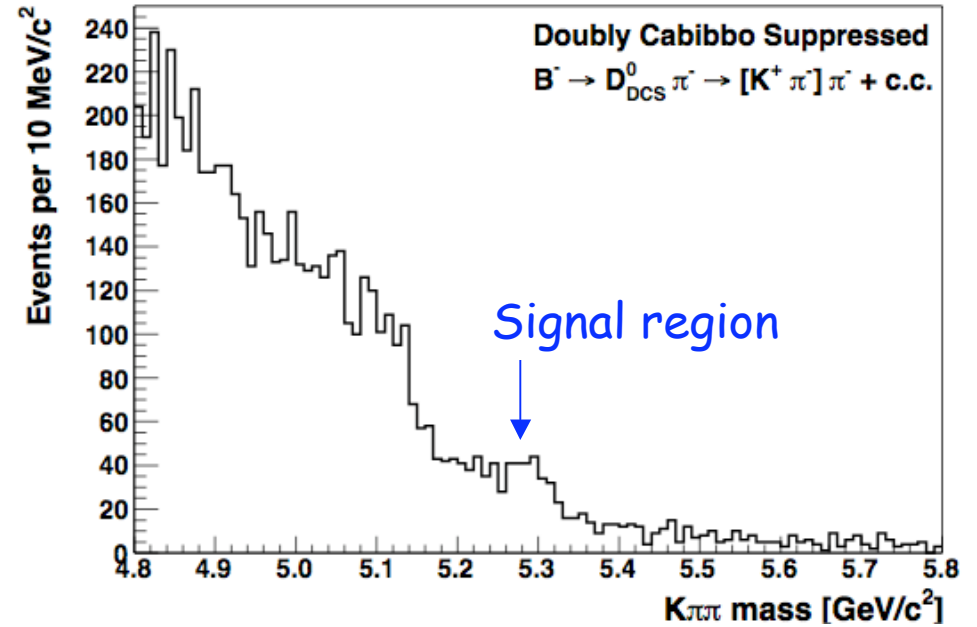
CF and DCS after cut optimization

$B^- \rightarrow D^0_{CF} \pi^- \rightarrow [K^- \pi^+] \pi^-$

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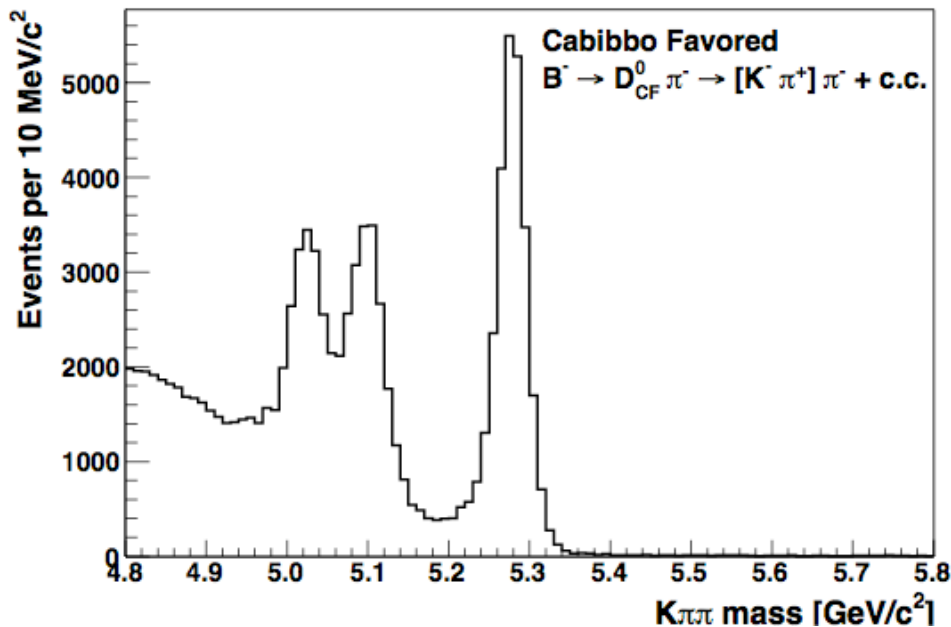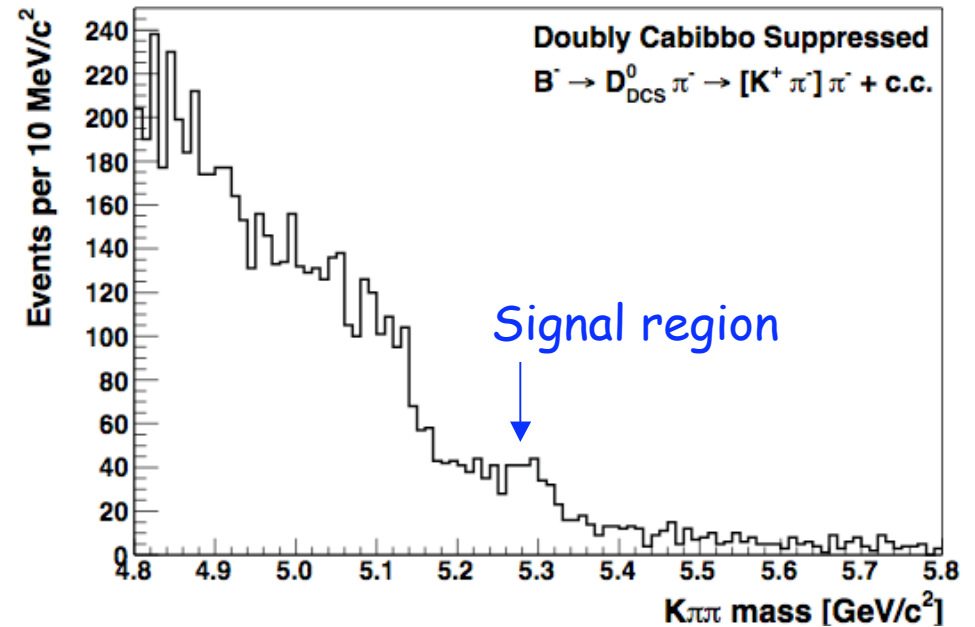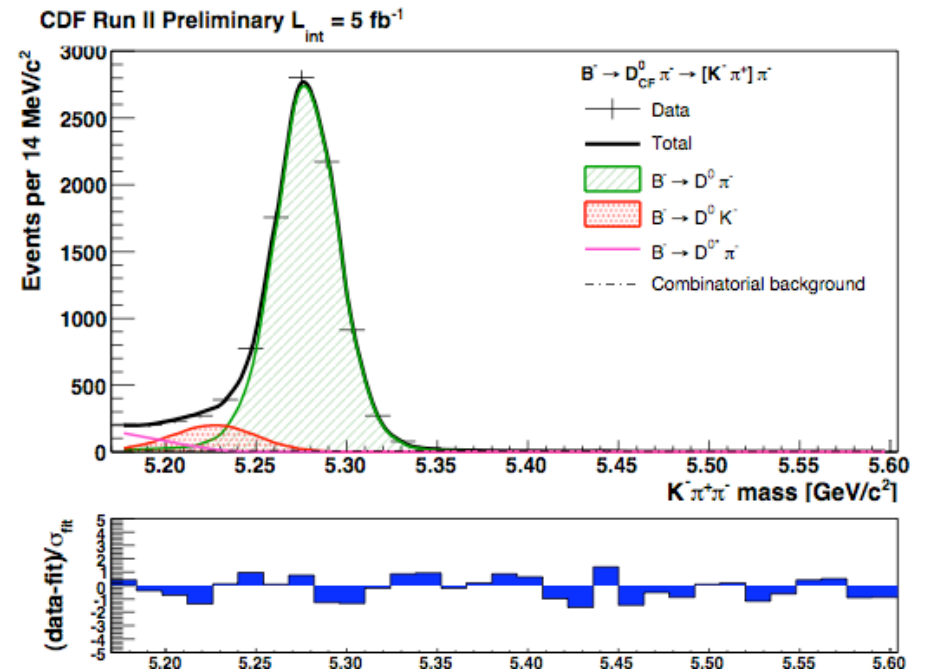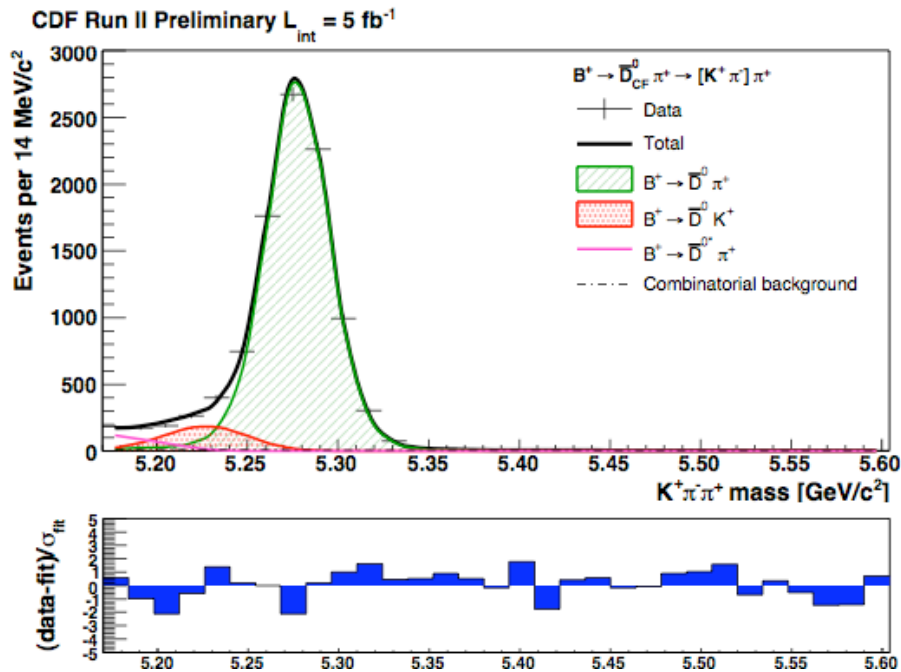

Fit procedure

Use of an *unbinned maximum likelihood fit* (combined on CF and DCS modes) to separate signals contribution using:

- mass information
- particle identification (dE/dx with K-π separation: 1.5 σ for p > 2 GeV/c)

Results: CF reconstruction

$B^+ \to \overline{D}^0_{CF} \pi^+ \to [K^- \pi^+] \pi^+$

$B^- \to D^0_{CF} \pi^- \to [K^+ \pi^-] \pi^-$

Yield $(B \to D_{CF}K) = 1513 \pm 68$ (5 fb^{-1})
Yield $(B \to D_{CF}\pi) = 17677 \pm 146$ (5 fb^{-1})

Results: DCS reconstruction

First reconstruction of DCS signals at a hadron collider.

$B^+ \to \overline{D}^0_{DCS} \pi^+ \to [K^- \pi^+] \pi^+$

$B^- \to D^0_{DCS} \pi^- \to [K^+ \pi^-] \pi^-$
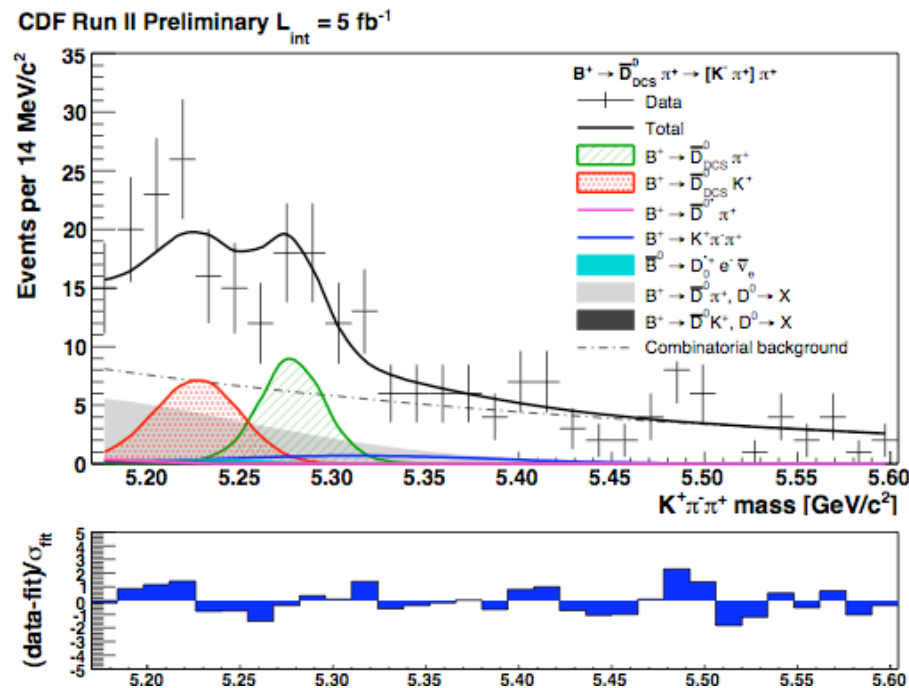
Yield (B $\to$ D$_{DCS}$K) = 34 ± 14 (5 fb^{-1})
Yield (B $\to$ D$_{DCS}\pi$) = 73 ± 16 (5 fb^{-1})
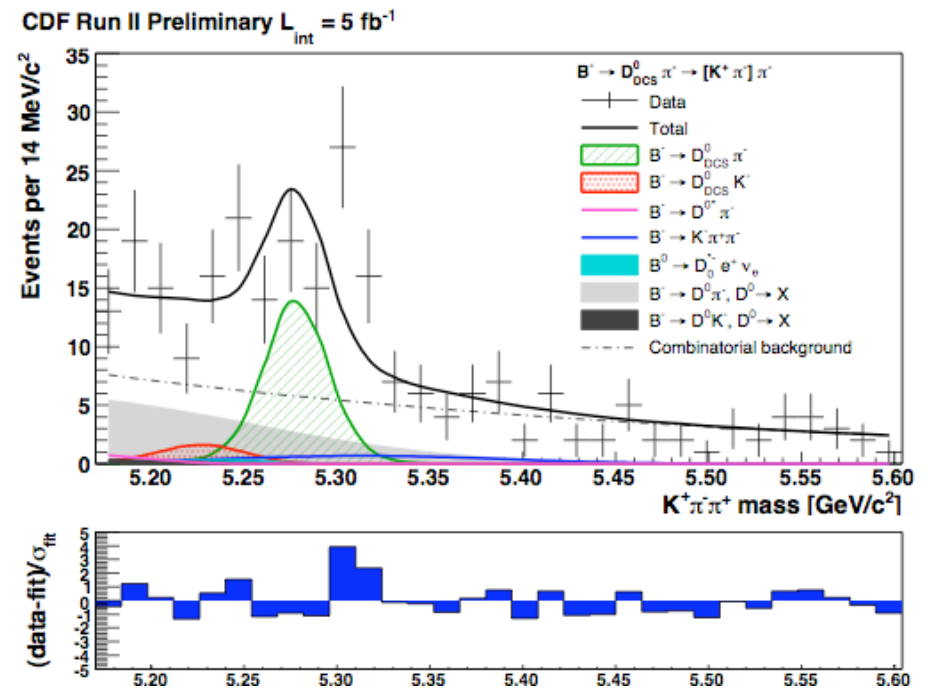
Significance for all DCS
signals (D$_{DCS}\pi$ + D$_{DCS}$K) > 5 σ

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Results: physics background

Physics background for DCS:

Decay	Yield
$B^- \to D^{0*}\pi^-$, $D^{0*} \to D^0\gamma/\pi^0$	3 ± 3
$B^- \to D^0\pi^-$, $D^0 \to X$	90 ± 13
$B^- \to D^0 K^-$, $D^0 \to X$	4 ± 3
$B^- \to K^-\pi^+\pi^-$	18 ± 4
$B^0 \to D_0^{*-} e^+ \nu_e$	4 ± 3

$B^+ \to \bar{D}^0_{DCS} \pi^+ \to [K^-\pi^+]\pi^+$
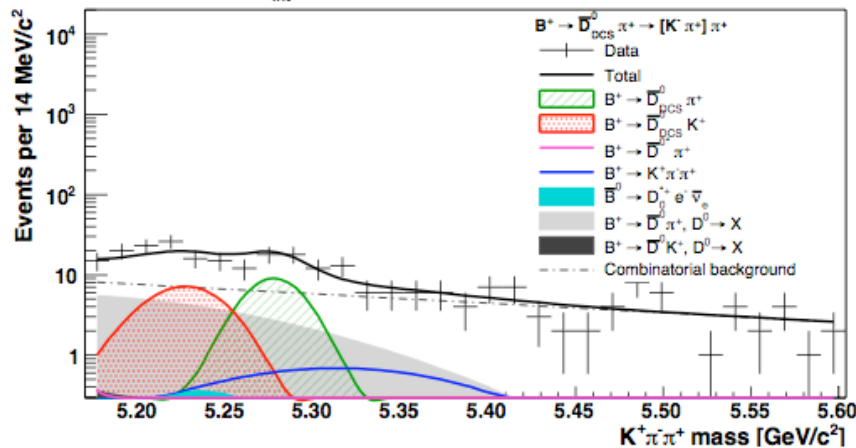
$B^- \to D^0_{DCS} \pi^- \to [K^+\pi^-]\pi^-$
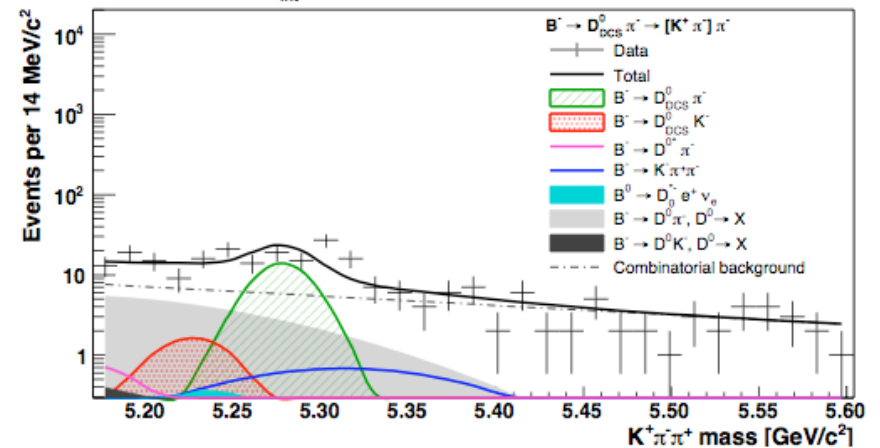
First measurement of A_{ADS} and R_{ADS}
at a hadron collider.

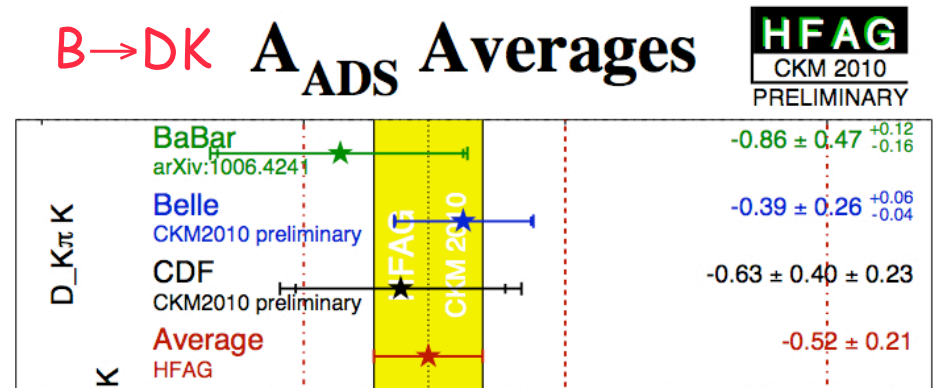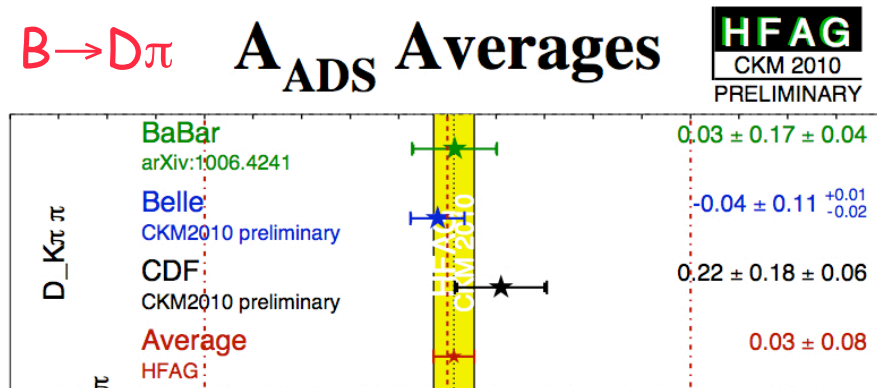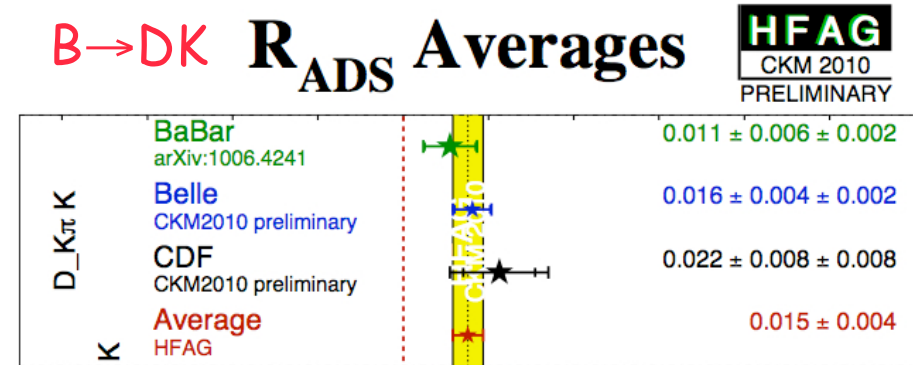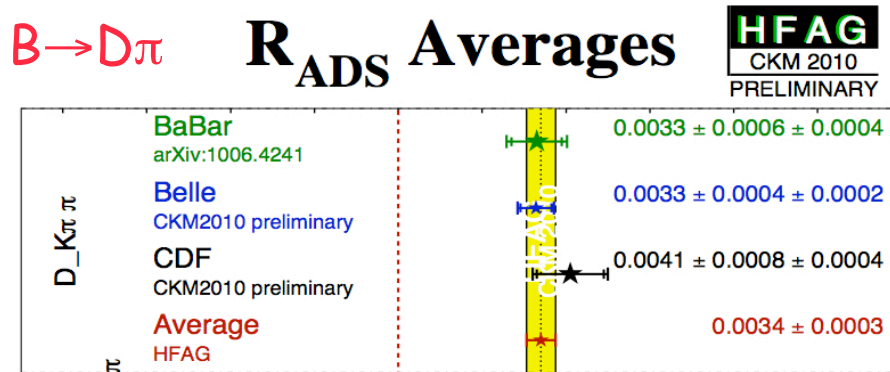$$R_{ADS}(\pi) = 0.0041 \pm 0.0008(stat) \pm 0.0004(syst)$$

$$A_{ADS}(\pi) = 0.22 \pm 0.18(stat) \pm 0.06(syst)$$

$$R_{ADS}(K) = 0.0225 \pm 0.0084(stat) \pm 0.0079(syst)$$

$$A_{ADS}(K) = -0.63 \pm 0.40(stat) \pm 0.23(syst)$$

(CDF public note 10309)

The results are in agreement and compatible with B-factories

The ADS measurement belongs to a *broader program of CDF for measuring γ from trees.*

Recently published the **GLW measurement** using 1 fb^{-1} of data *(Phys.Rev.D81:031105,2010)*

The GLW method

- Direct CP violation in $B \rightarrow D_{CP}K$ modes
  ($D_{CP+} \rightarrow \pi^+ \pi^-$, $K^+ K^-$ and $D_{CP-} \rightarrow K^0_s \pi^0$, $K^0_s \omega$, $K^0_s \phi$.)
- very clean method
- small asymmetry, sensitivity to γ proportional to r_B

The observables

$$R_{CP\pm} = \frac{\Gamma(B^- \rightarrow D^0_{CP\pm}K^-) + \Gamma(B^+ \rightarrow D^0_{CP\pm}K^+)}{[\Gamma(B^- \rightarrow D^0K^-) + \Gamma(B^+ \rightarrow D^0K^+)]/2}$$

$$A_{CP\pm} = \frac{\Gamma(B^- \rightarrow D^0_{CP\pm}K^-) - \Gamma(B^+ \rightarrow D^0_{CP\pm}K^+)}{\Gamma(B^- \rightarrow D^0_{CP\pm}K^-) + \Gamma(B^+ \rightarrow D^0_{CP\pm}K^+)}$$

From theory:

$R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma$

$A_{CP\pm} = 2r_B \sin\delta_B \sin\gamma / R_{CP\pm}$

3 independent equations
($A_{CP+}R_{CP+} = -A_{CP-}R_{CP-}$)
and **3 unknowns** (r_B, γ, δ_B)

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Results

D mode	$B^+ \to D\pi^+$	$B^- \to D\pi^-$	$B^+ \to DK^+$	$B^- \to DK^-$
$K^-\pi^+$	3769 ± 68	3763 ± 68	250 ± 26	266 ± 27
K^+K^-	381 ± 25	399 ± 26	22 ± 8	49 ± 11
$\pi^+\pi^-$	101 ± 13	117 ± 14	6 ± 6	14 ± 6

Yield $(B \to D_{CP+}K) \sim 90$ $(1\ fb^{-1})$
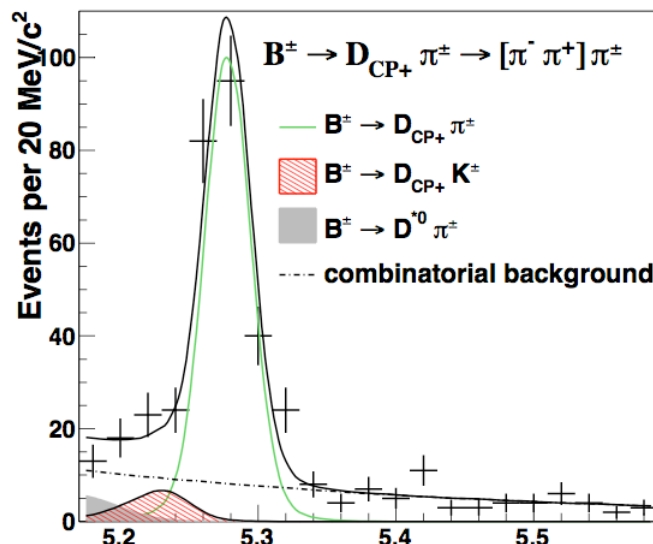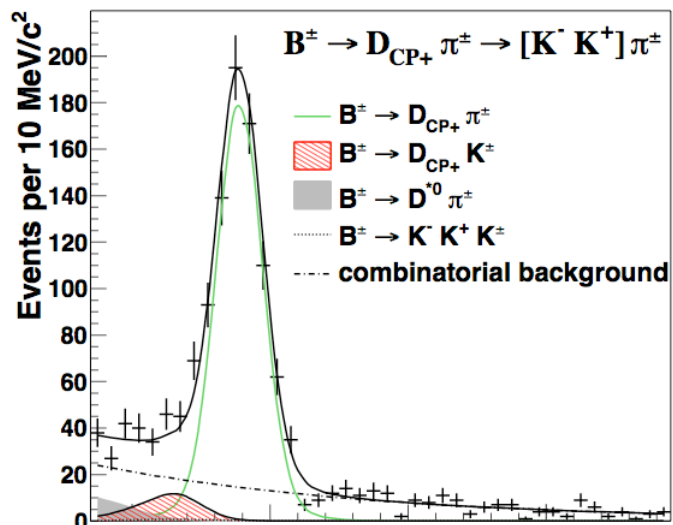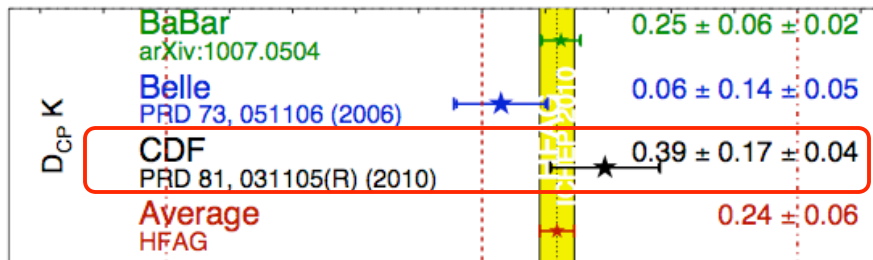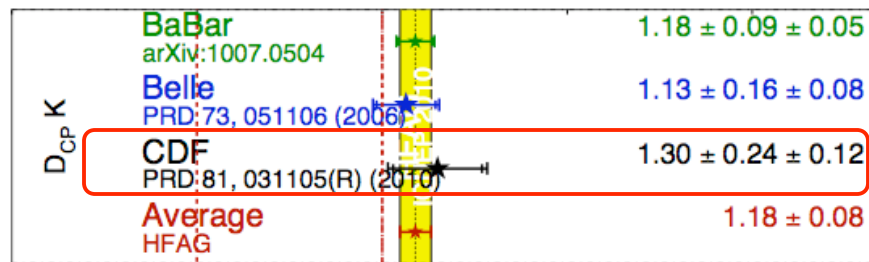
- CDF performed:
  - first measurement of A_{ADS} and R_{ADS} at a hadron collider using 5 fb^{-1}.
    - Significance of DCS signals ($D_{DCS} \pi + D_{DCS} K$) > 5σ

  - first measurement of A_{CP+} and R_{CP+} at a hadron collider using 1 fb^{-1}.

- Demostrated **capability** of hadron collider with **B to charm decays**. The results are competitive with B-factories

- While B-factories updated the measurement to all dataset available, CDF expect to **double the data-set** by 2011 and give significant updates soon.

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BACK-UP

From an LHCb study: resolution on γ (assuming 2fb^{-1})

B mode	D mode	Method	$\sigma(\gamma)$
B$^+\rightarrow$DK$^+$	Kπ +KK/$\pi\pi$ + K$\pi\pi\pi$	ADS+GLW	5°-15°
B$^+\rightarrow$D*K$^+$	Kπ	ADS+GLW	under study
B$^+\rightarrow$DK$^+$	K$_S\pi\pi$	Dalitz	15°
B$^+\rightarrow$DK$^+$	KK$\pi\pi$	4-body "Dalitz"	15°
B$^+\rightarrow$DK$^+$	K$\pi\pi\pi$	4-body "Dalitz"	under study
B$^0\rightarrow$DK^{*0}	Kπ + KK + $\pi\pi$	ADS+GLW	7°-10°
B$^0\rightarrow$DK^{*0}	K$_S\pi\pi$	Dalitz	under study
B$_S\rightarrow$D$_S$K	KKπ	tagged, A(t)	13°
B $\rightarrow \pi\pi$,KK			4°-10°

Signal only, no accept. effect

When statistics becomes sufficiently large to actually **see** the **B->DK DCS** decay, the most sensitive method for measuring gamma becomes **ADS** (+GLW), not Dalitz.

Separating DK from other modes

$$B^- \rightarrow D^0_{CF} \pi^- \rightarrow [K^- \pi^+] \pi^-$$

MC

DATA
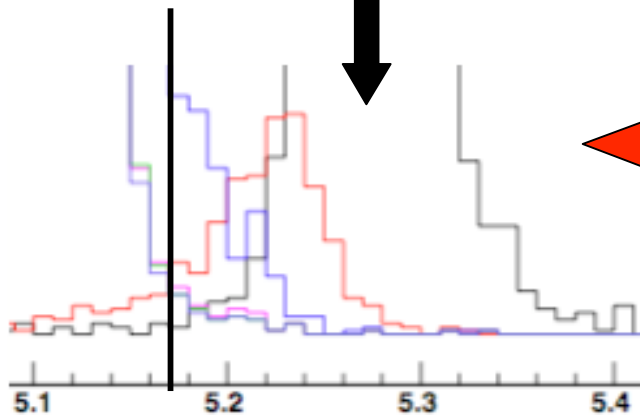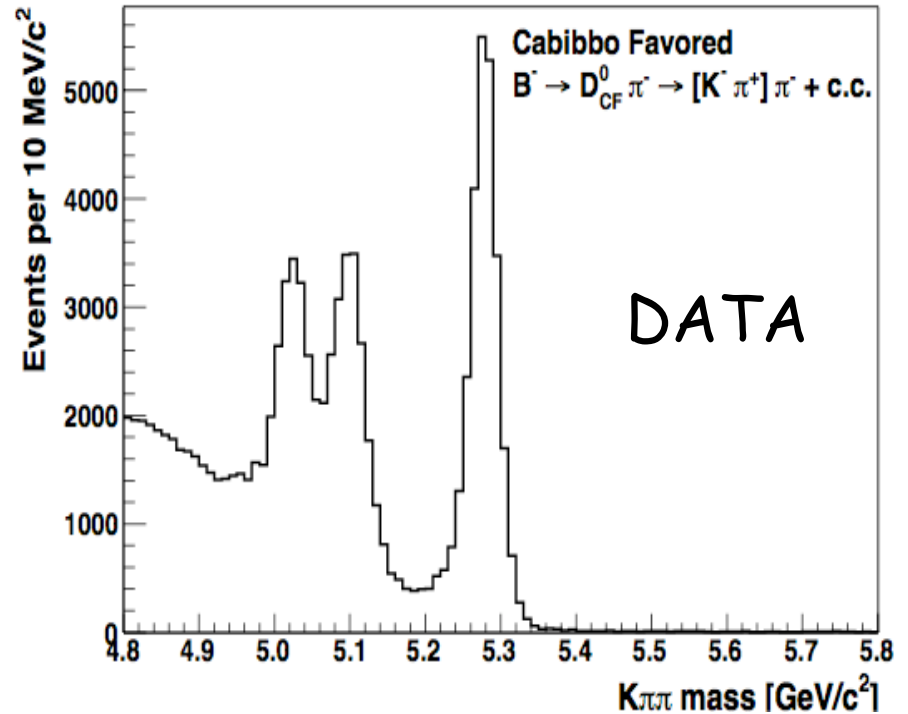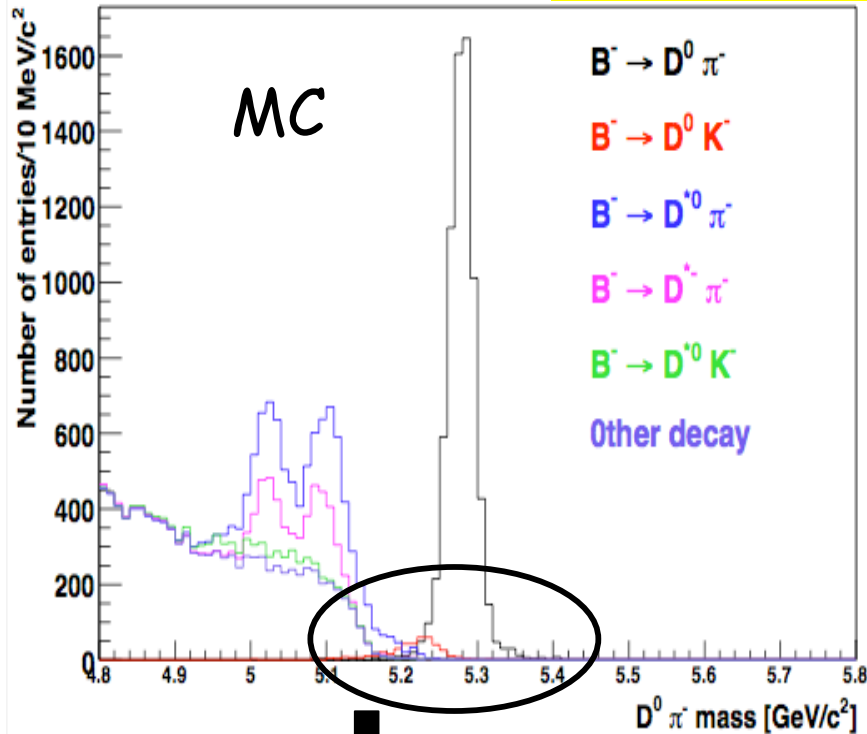
To reject most of the physical backgrounds, narrow fit windows [5.17,6.5]

The only significant physics backgrounds are $B^- \rightarrow D^0 \pi^-$ and $B^- \rightarrow D^{0*} \pi^-$

Separation by Particle ID

Implementation of a Likelihood FIT using **masses** and **particle identification** (dE/dx) information to determine the signal composition

CDF Run II Preliminary
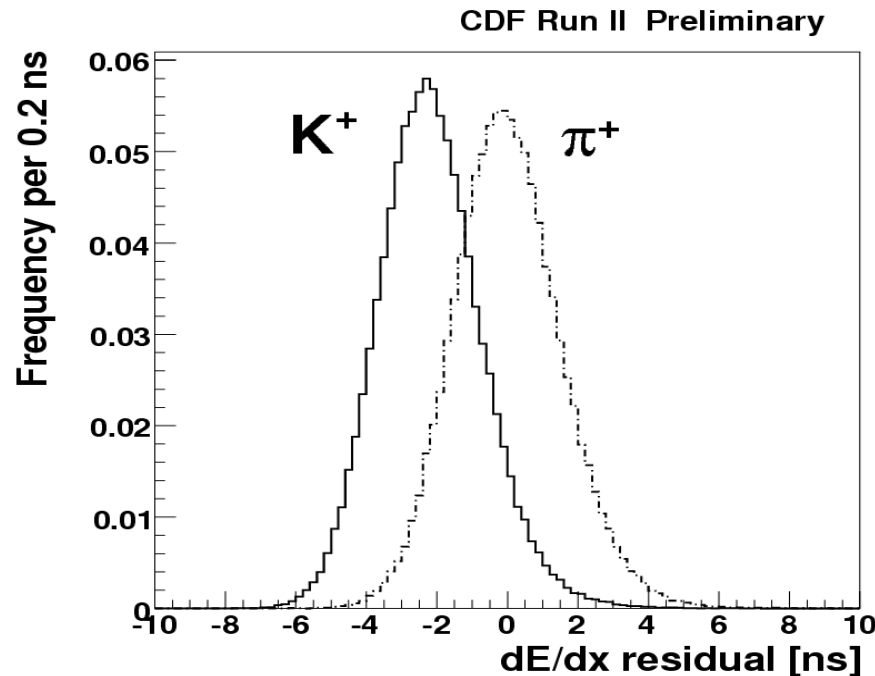
K − π separation: 1.5 σ for p > 2 GeV/c

ADS: Systematics

Source	$R_{ADS}(\pi)$	$R_{ADS}(K)$	$A_{ADS}(\pi)$	$A_{ADS}(K)$
dE/dx	0.0001	0.0050	0.0560	0.070
combinatorial background	0.0003	0.0037	0.0073	0.153
$B^- \to [X]_D \pi^-$ shape	0.0002	0.0025	0.0067	0.057
$B^- \to [X]_D K^-$ shape	-	0.0001	0.0003	0.003
$B^- \to K^- \pi^+ \pi^-$ shape	0.0001	0.0004	0.0049	0.009
$B^0 \to D_0^{*-} e^+ \nu_e$ shape	-	0.0003	0.0020	0.007
$B^- \to D^{*0} \pi^-$ shape	-	0.0005	0.0009	0.013
efficiency	-	0.0001	-	0.003
bias	0.0001	0.0042	0.0159	0.148
Total	**0.0004**	**0.0079**	**0.059**	**0.232**

ADS: Likelihood

$$\mathcal{L} = \mathcal{L}_{CF+} \cdot \mathcal{L}_{CF-} \cdot \mathcal{L}_{DCS+} \cdot \mathcal{L}_{DCS-}$$

$$\mathcal{L}_{CF+} = \prod_i^{Nevents} \Big[(1 - b_{CF+}) \cdot \Big(f_\pi^{CF+} \cdot pdf_\pi(M, ID) + \mathbf{c}^+ \cdot f_\pi^{CF+} \cdot pdf_{D*}(M, ID) +$$
$$+ \Big(1 - f_\pi^{CF+} - \mathbf{c}^+ \cdot f_\pi^{CF+} \Big) \cdot pdf_K(M, ID) \Big) + b_{CF+} \cdot pdf_{comb}(M, ID) \Big]$$

$$\mathcal{L}_{DCS+} = \prod_i^{Nevents} \Big[(1 - b_{DCS+}) \cdot \Big(f_\pi^{DCS+} \cdot pdf_\pi(M, ID) + \mathbf{c}^+ \cdot f_\pi^{DCS+} \cdot pdf_{D*}(M, ID) +$$
$$+ \Big(1 - f_\pi^{DCS+} - \mathbf{c}^+ \cdot f_\pi^{DCS+} \Big) \cdot pdf_K(M, ID) \Big) +$$
$$+ b_{DCS+} \cdot \Big(f_{[X]\pi}^+ \cdot pdf_{[X]\pi}(M, ID) + f_{[X]K}^+ \cdot pdf_{[X]K} + f_{K\pi\pi}^+ \cdot pdf_{K\pi\pi}(M, ID) +$$
$$f_{B^0}^+ \cdot pdf_{B^0}(M, ID) + (1 - f_{[X]\pi}^+ - f_{[X]K}^+ - f_{K\pi\pi}^+ - f_{B^0}^+) \cdot pdf_{comb}(M, ID) \Big) \Big]$$

Analogous expressions for negative charges

- $pdf_i(M, ID) = pdf_i(M) * pdf_i(ID)$
- **Fitted parameters**
  - $b_{CF, DCS}$ = background fraction for CF and DCS
  - $f_{\pi, CF, DCS}$ = B->D^0 π fraction for CF and DCS signal
  - $c = f_{D*}/f_\pi$ (equal for CF and DCS)
  - $f_{[X]\pi}$ = fraction of B->D^0 π, D^0->X in DCS reconstruction (constrained from MC)
  - $f_{[X]K}$ = fraction of B->D^0K, D^0->X in DCS reconstruction (constrained from MC)
  - $f_{K\pi\pi}$ = fraction of B->K^- π^+ π^- in DCS reconstruction (constrained from MC)
  - f_{B0} = fraction of B^0->D*- e ν in DCS reconstruction (constrained from MC)

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